Wide Bandgap Semiconductor Technology

For Energy Efficiency

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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- PowerAmerica
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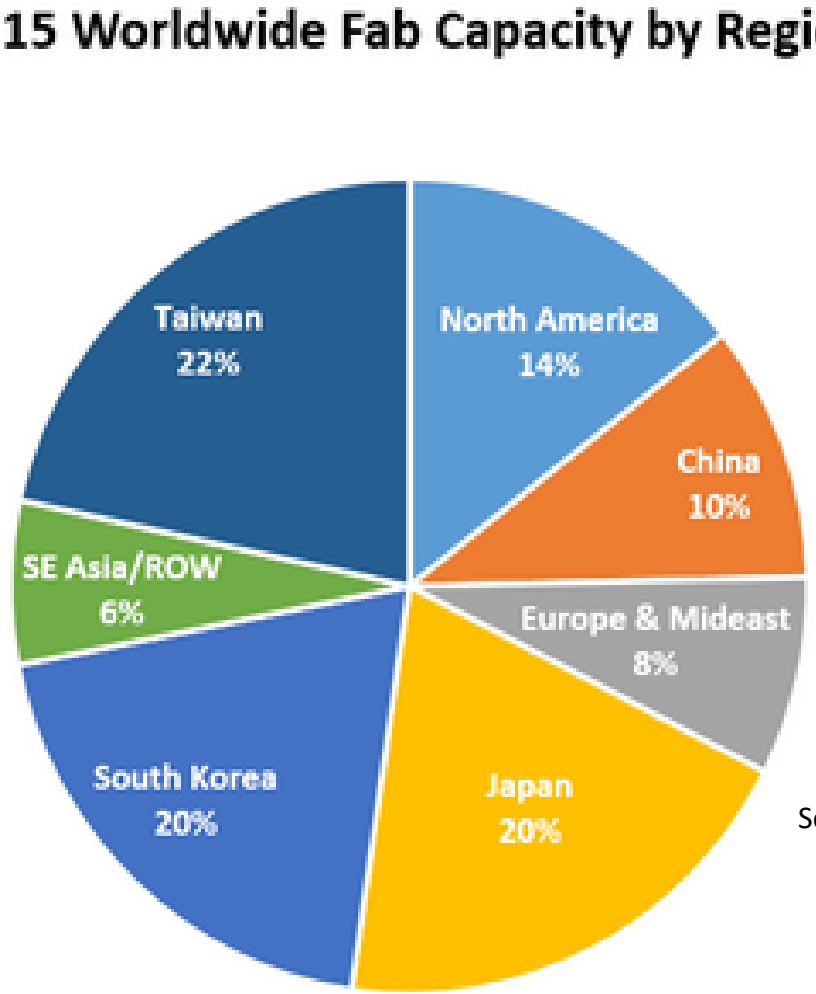
- Department of Energy
  - Mark Johnson
  - Robert Ivester
  - Steven Boyd

Presentation Outline

- Decline of Si Manufacturing Industry in U.S.
- PowerAmerica Institute
  - Foundry Model
  - Work Force Development
- Cost of SiC Components
- Cosmic Ray Ruggedness of SiC
- Graduate Traineeships
- Achieving >50% Renewable Grid
  - Significance of High Voltage SiC Devices

US Manufacturing Challenge

U.S. Semiconductor Industry



Source: SEMI (www.semi.org)

Historical Perspective

- 1960s
  - U.S. Semiconductor industry begins offshoring labor intensive manufacturing operations.
- 1970s-1980s
  - Increased offshoring of complex operations, including wafer fabrication, design work and R&D.
- 2007
  - Only 8% of all new semiconductor fabrication plants under construction in the world were located in the U.S.
  - 12% of new fabrication plants were being built in China, 40% in Taiwan, and 6% in South Korea.
  - United States produced 17% of the world output of semiconductors, in 1995 the U.S. accounted for 23% of the global output
- 2009
  - 16 Fabs began construction throughout the world, only 1 in the U.S.
  - United States down to 14% of global semiconductor production

PowerAmerica

Vision

Energy savings through deployment of WBG Power Electronics & Development of a Manufacturing Base in the US through:

- **Achieving low prices of WBG devices in 5 years**
- **Training Graduate students in the use of WBG Semiconductors**

PowerAmerica started operations on Feb. 01, 2015 with $140 M funding over 5 years

Barriers to Acceptance of WBG Technologies

- ***High Cost of WBG Chips***
  - Lower systems cost arguments don't work with 10x higher semiconductor cost

  Must reduce cost of WBG Semiconductors – Achieve 10 cents/Amp for 1.2 kV Switches in 5 years

- ***PE Community slow to change and adapt new technologies***
  - Lack of experience with WBG semiconductors
  - False perceptions of poor reliability of WBG semiconductors

  Must train Graduate students to use WBG devices in Power Electronics

Current and Pending PowerAmerica Partners

Institute Lead

North Carolina State University

Universities

Arizona State University
Florida State University
Kettering University
Rensselaer Polytechnic Institute
University of California, Santa Barbara
University of California, Davis
Virginia Polytechnic Institute

Laboratories

National Renewable Energy Laboratory
U.S. Naval Research Laboratory
Argonne National Laboratory

Industry

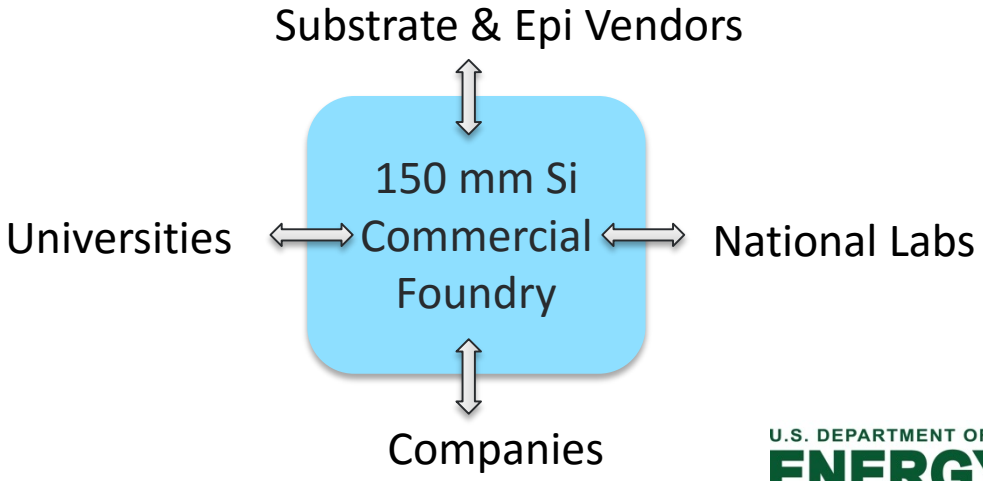
ABB
AgileSwitchAtom Power
CoolCad Electronics
Delphi
GeneSiC
John Deere Electronic Solutions
Lockheed Martin
Monolith Semiconductor
Navitas
Power Electronics Industry Collaborative
Qorvo
Raytheon
Toshiba
Transphorm
United Silicon Carbide, Inc
Wolfspeed (formerly CREE + APEI)
X-Fab

Pending

Auburn University
General Motors – Powertrain
InnoCit
The Ohio State University

Goal: Achieve 10 ¢/A for 1.2 kV Switches in 5 yrs

- **Combine common Si and SiC process lines**
  - **90% are the same**
- **Aggregate Substrate and Epi demand to negotiate better pricing**
- **Innovation through design**
- **Reduce technology risk, encourage investments by VC firms - $10-15 M is required to create a product as opposed to $200 M**



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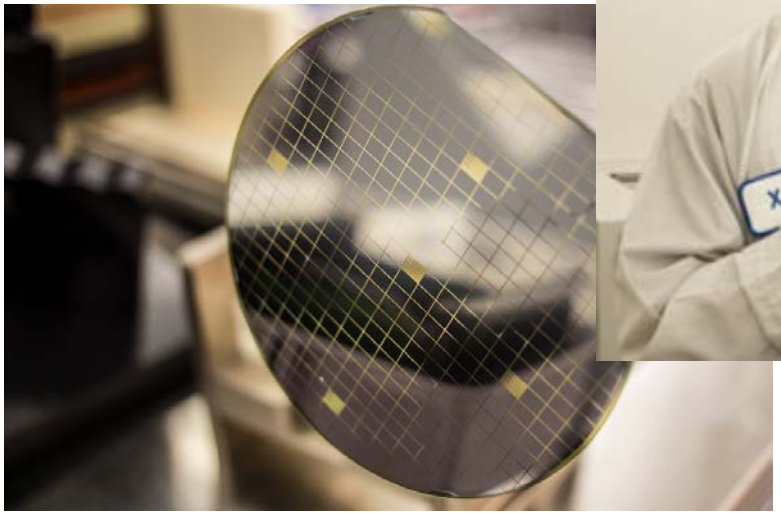
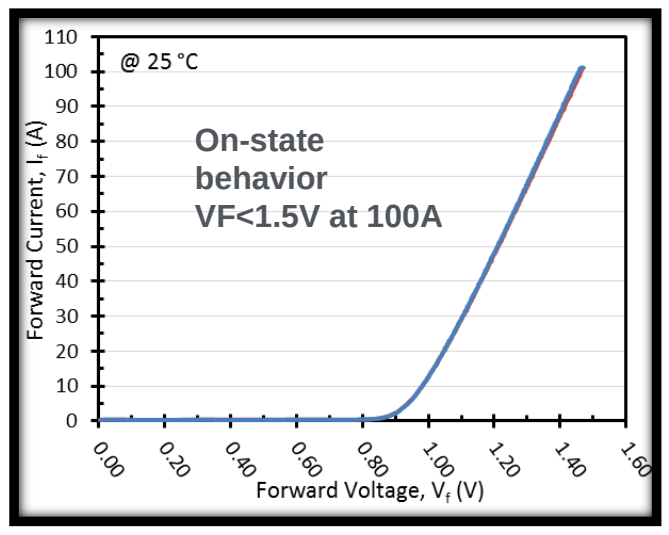
PowerAmerica SiC Foundry Pricing Targets

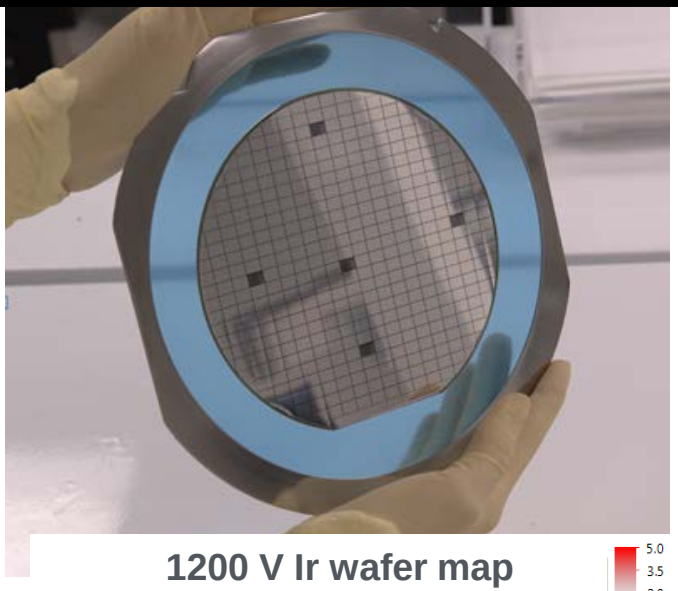
- X-FAB now '**SiC-ready**'; capable of providing complete SiC Manufacturing
- Target
  - $850/wafer process cost in low volumes
  - $500/wafer process cost in high volumes

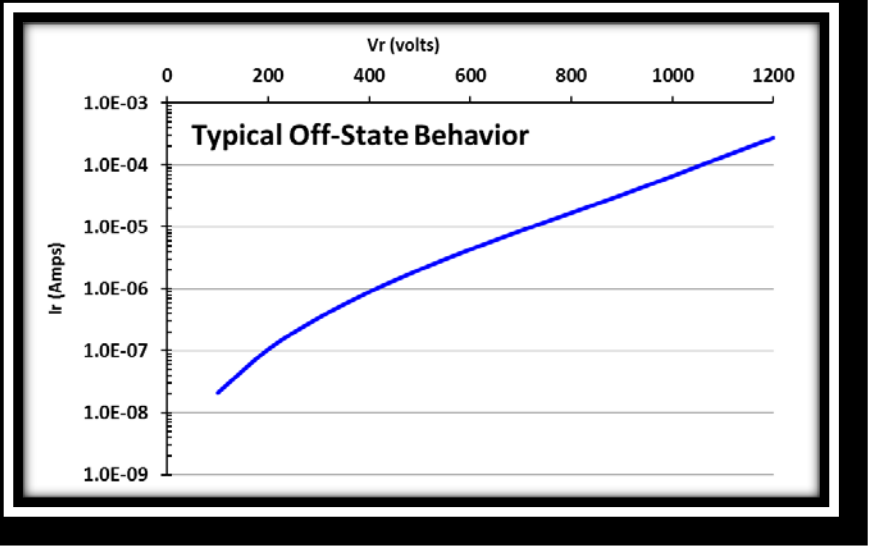


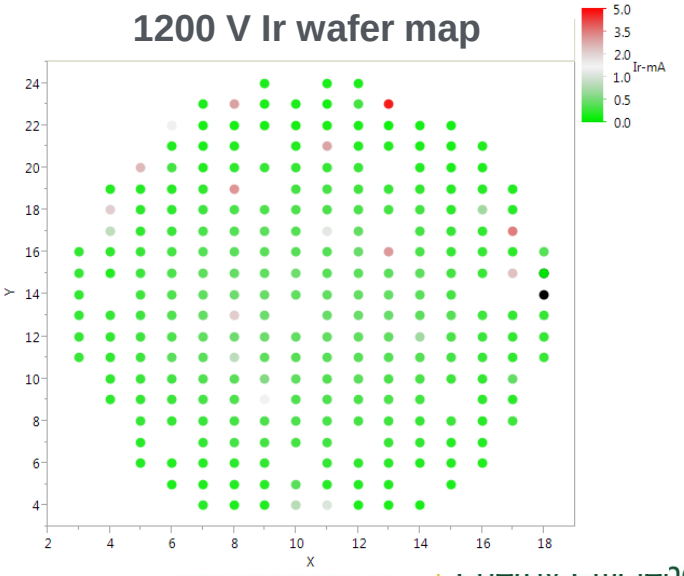
6" SiC wafer at X-FAB

6inch Foundry Development
Large Area JBS Diodes 100A, 1200V









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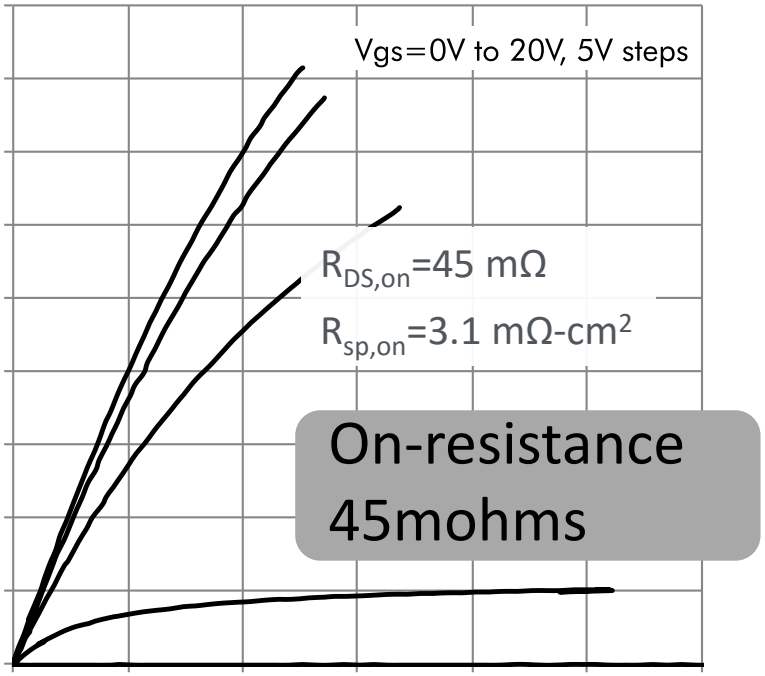
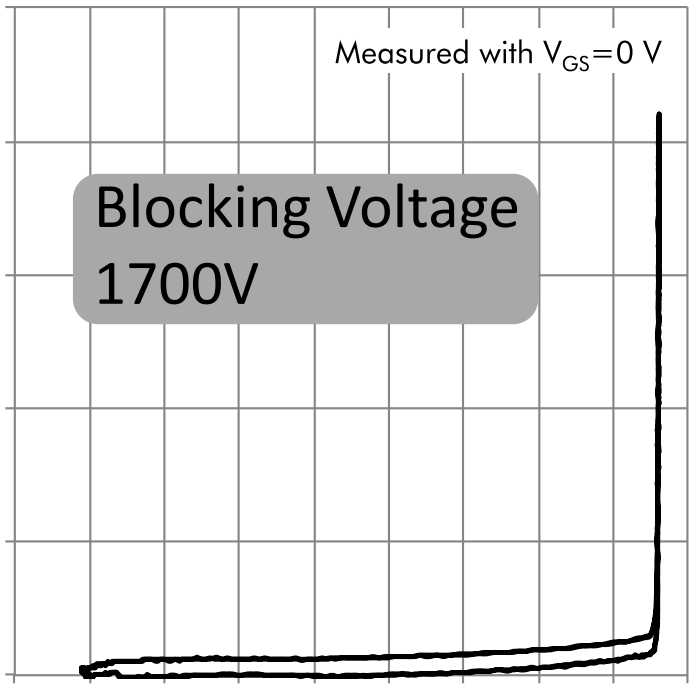
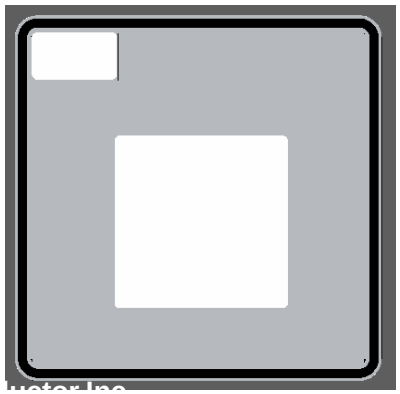
MOSFETs fabricated in 150mm Si foundry

Monolith Semiconductor Inc.







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PowerAmerica Success

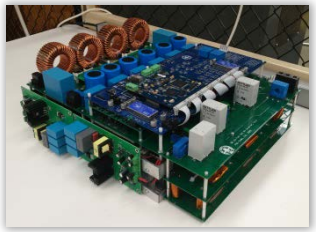
Stories in Power Electronics

SiC PV Converter

1x

Best Si commercial PV converter (~0.8 kW/kg)

3x



FSU Gen-I SiC PV converter prototype (~2.5 kw/kg)

6x

FSU Gen-II SiC PV converter conceptual design (~5 kW/kg)

Gen- I SiC PV converter

- ✓ 2.5 kW/kg, 22.7 W/in^3
- ✓ Peak efficiency 99%
- ✓ SiC T-type module (Wolfspeed)
- ✓ Filter-less at grid side
- ✓ Low CM voltage

Cost reduction with FSU SiC PV converter:

- Maintenance, installation, transportation and storage cost ⇩ - smaller & lighter
- Filter, enclosure, heatsink cost ⇩ - less metal
- Development & manufacturer cost ⇩ -scalable
- Fault related energy loss ⇩ - more stable

Education/Training:

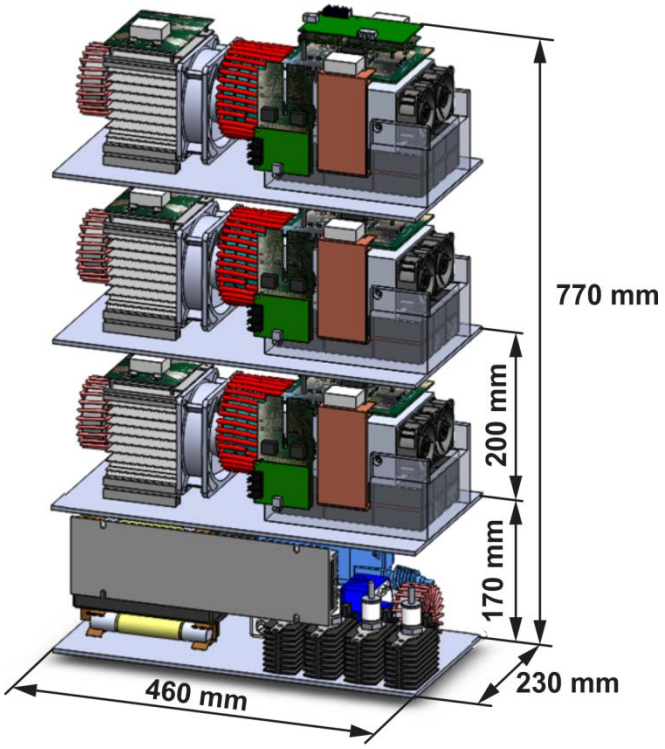
- 5 graduate students performing
  - Device characterization and protection
  - Magnetic components design
  - High sample-rate control and software design
  - Low parasitic PCB design

Medium Voltage WBG EV Fast Charger

NC STATE UNIVERSITY

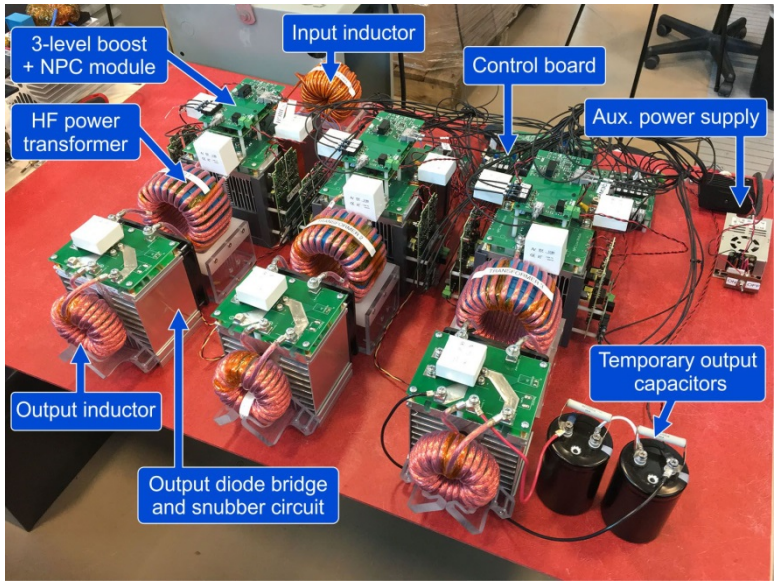
PowerAmerica

- **Objective:** Develop a modular medium voltage WBG EV Fast Charger using SiC semiconductor power devices to exploit the advantages of using WBG Devices



Prototype Rendering
& Hardware Implementation

- MV WBG Fast charger
  - 50kW; 2,400Vac to 400Vdc
  - η≥95%, PF≥0.98, THD ≤ 2%
  - 10 x size reduction; 4x weight reduction
  - Simple install w/o step-down transformer



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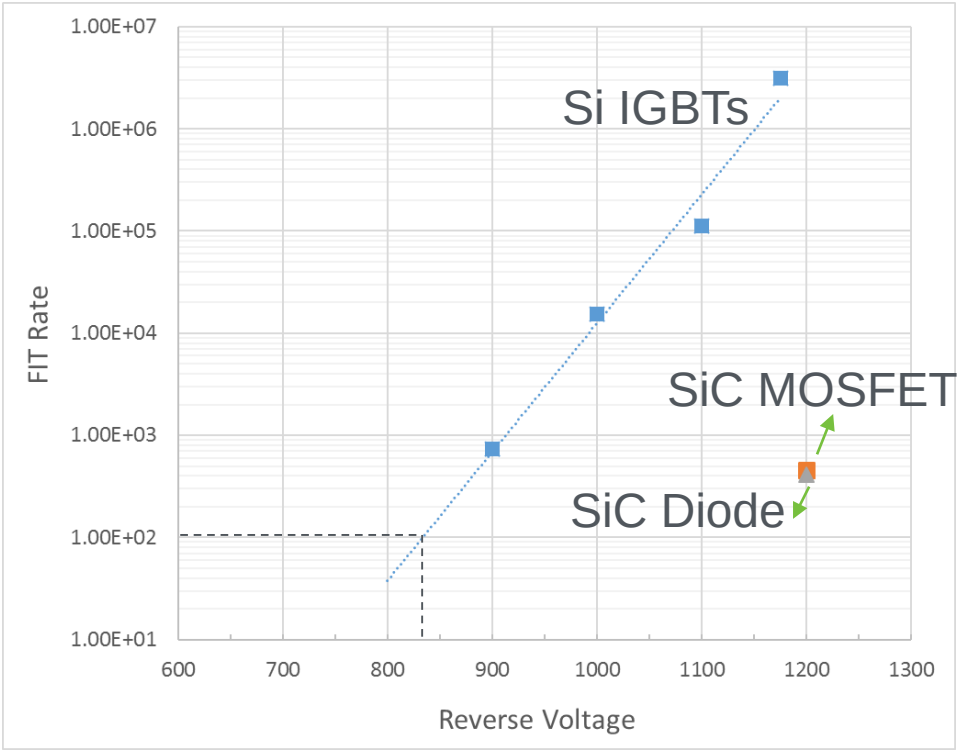
Cosmic Ray Ruggedness of WBG

TCR Testing of 1200V SiC MOSFETs and Diodes

Monolith Semiconductor Inc.

SBIR Project



No failures were observed on SiC devices. FIT rate was calculated assuming one fail after 6 months of testing for comparison with Si IGBT failure data

- Terrestrial cosmic radiation induced failures observed on 1200V Si IGBTs at four different voltages
- To achieve a FIT rate of 100, 1200V Si IGBTs cannot be biased > 800V
- **No failures were observed on 1200V SiC MOSFETs or Diodes after testing for 6 months (over 2 million device hours) at rated voltage of 1200V!**
- Testing will continue on both 1200V SiC MOSFETs and diodes
- Future work should also focus on radiation hardness of SiC devices for space applications

Traineeships

Wide Bandgap Traineeship--$ 5M for 5 Yrs

- **Purpose**
  - Provide hands-on training of students in WBG power electronic devices and their application.
- **Benefits**
  - Ensure a pipeline of well-trained professionals entering industry and academia
  - Enable a 'chain reaction' of higher education in WBG technology for decades

University of Tennessee

Virginia Polytechnic Institute

Program Impact:

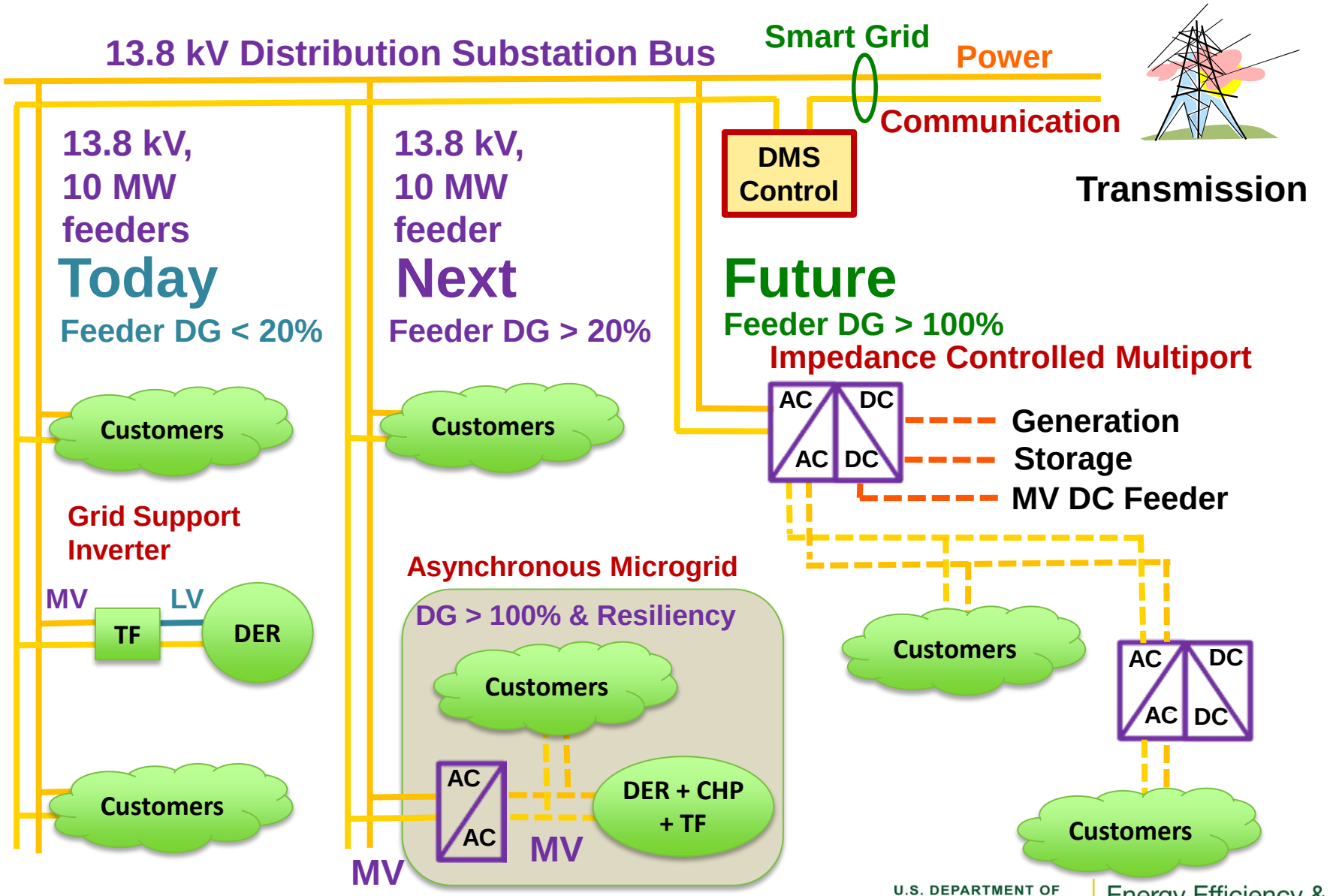
- >45 U.S. citizen M.S. and Ph.D. graduates in power engineering over 5 years
- 7 new graduate courses developed focusing on WBG
  - Converters, electrical systems packaging, WBG characterization and applications
- Students involved with National Laboratory and Industrial Internships

Goal: Train at least 100 Graduate students in 5 years

Renewable Challenge And HV Devices

Hurricane Sandy, Oct. 2012, 285 People Dead, $75 B loss

High Penetration Distributed Generation



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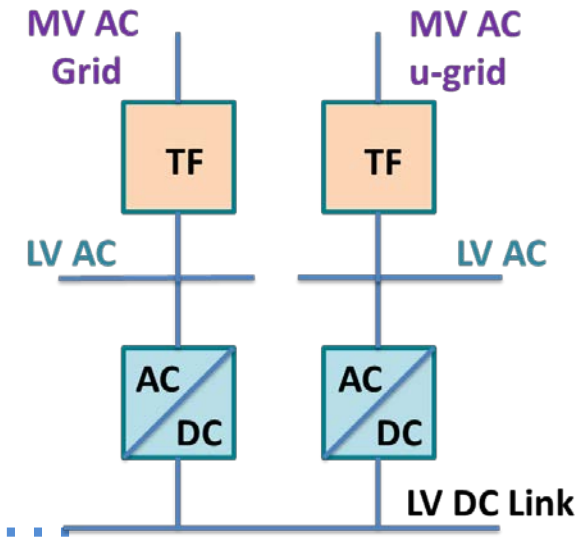
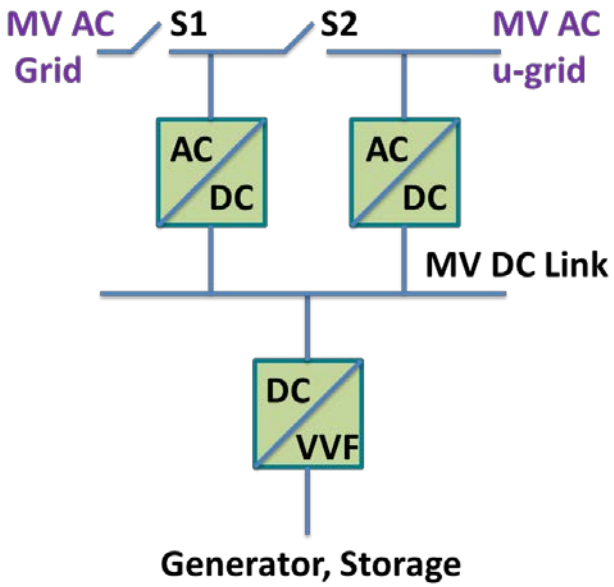
HV SiC makes 100% Renewable Energy Affordable

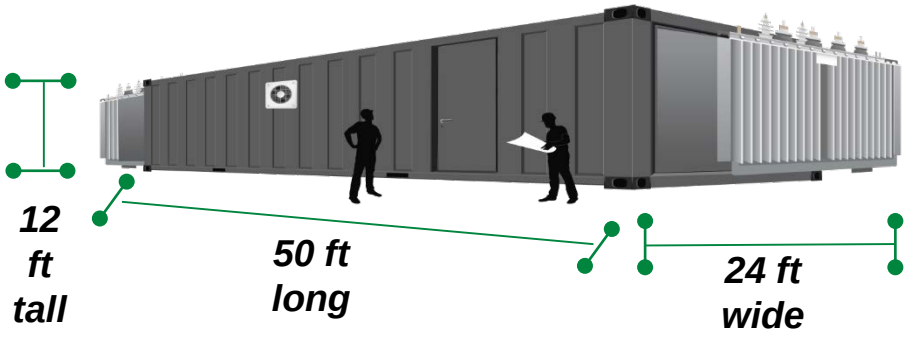
Silicon Solution



SiC Solution



Example installation: 2 x 5 MVA



HV-HF SiC Modules enable:

- Much Smaller Size and Weight (10x)
- Lower Cost Potential
- Better Performance
  - Lower impedance
  - Higher bandwidth

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Summary

- Approaching a Global Energy 'tipping' point
  - Urgent need for reducing GHG
  - Expansion of Renewable Sources is critical
  - HV SiC devices necessary for realization
- Fabless foundry Model ***WILL*** reduce WBG prices and accelerate market adoption
- Next Big Markets: Transportation, Data Servers and Variable Speed Drives for MW Motors
- Educational Initiatives- essential for future workforce